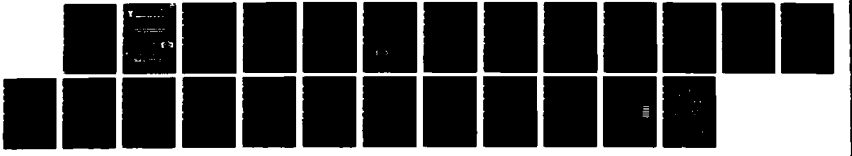
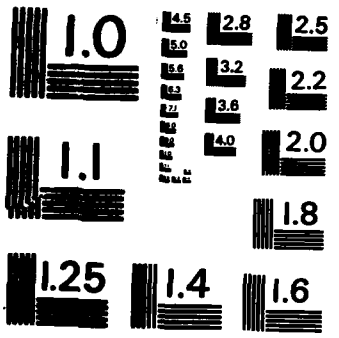
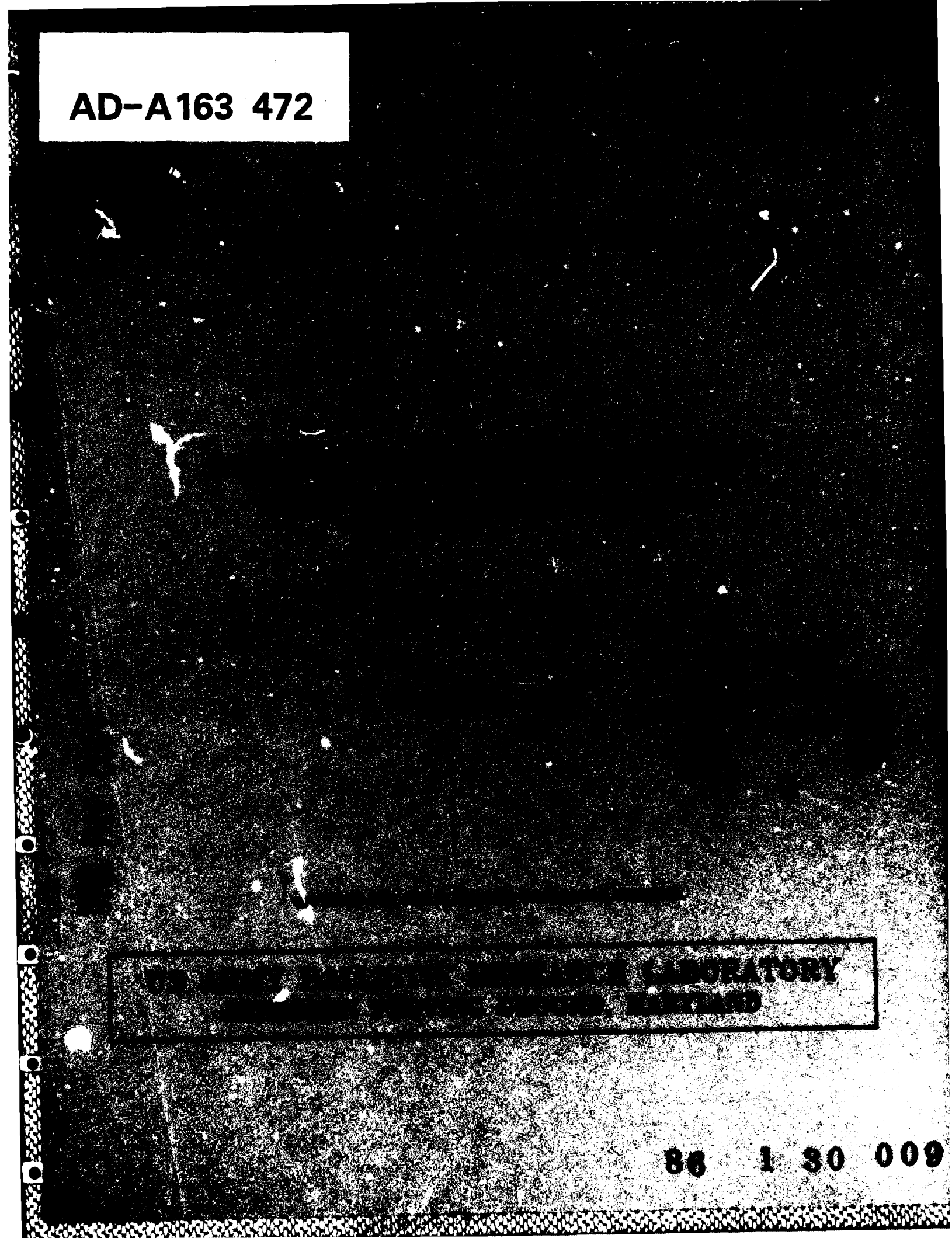
AD-A163 472 RADICAL FLUORESCENCE STUDIES WITH LIQUID PROPELLANTS 1/1
(U) ARMY BALLISTIC RESEARCH LAB ABERDEEN PROVING GROUND
MD R A BEYER DEC 85 BRL-MR-3488

UNCLASSIFIED F/G 19/1 NL







Destroy this report when it is no longer needed.
Do not return it to the originator.

Additional copies of this report may be obtained from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

The use of trade names or manufacturers' names in this report does not constitute indorsement of any commercial product.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Memorandum Report BRL-MR-3488	2. GOVT ACCESSION NO. AD-A163472	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) RADICAL FLUORESCENCE STUDIES WITH LIQUID PROPELLANTS		5. TYPE OF REPORT & PERIOD COVERED Final 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Richard A. Beyer		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Ballistic Research Laboratory ATTN: SLCBR-IB Aberdeen Proving Ground, MD 21005-5066		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 1L161102AH43
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Ballistic Research Laboratory ATTN: SLCBR-DD-T Aberdeen Proving Ground, MD 21005-5066		12. REPORT DATE December 1985 13. NUMBER OF PAGES 21
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION DOWNGRADING SCHEDULE N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Liquid Propellants
Hydroxylammonium Nitrate
Isopropylammonium Nitrate
Fluorescence
Radicals
Laser Induced Fluorescence
Imaging

20. ABSTRACT (Continue on reverse side if necessary and identify by block number) meg

Radical fluorescence emission has been characterized for the combustion of typical liquid monopropellants composed of hydroxylammonium nitrate, an aliphatic ammonium nitrate, and water. Ignition of the samples was done by injection of a spray into a hydrogen-air diffusion flame. Positive identification was made of the following key radical species: NH, CN, C_2, CH, and NO_2. Possible signals from NH_2 were also observed. The OH radical, already present in the flame, gave diminished emission due to the cooling

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. Abstract (Cont'd):

effect of the LP on these flames at atmospheric pressure. NCO was likely present, but would not have been observed under the conditions of these observations. From the convolution of light intensity and detector response, the radical CN is the clear choice for maximum signal-to-noise ratio. Preliminary two-dimensional imaging of the fluorescence was done to demonstrate the utility of the technique for the study of liquid propellant sprays. Thus, the probability of success for active laser probing of LP spray combustion looks excellent, with the prime candidate for probing being the CN molecule. Other candidates such as $C_2^{(1}$ and $NO_2^{(1}$ are possible candidates with continuous or high rate metal vapor lasers.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I. INTRODUCTION

In the development of liquid propellants for regenerative guns, the physical location of ignition and combustion of a jet or spray of propellant as it enters the combustion chamber can provide insight into the rate of energy release in these systems. Typical traditional methods of studying such phenomena are high-speed photography and shadow or schlieren techniques. While much can be learned with these techniques, they can be limited by their inherent line-of-sight characteristics. An alternative approach is to use a technique which has been recently demonstrated and developed to a practical level in many combustion systems: two-dimensional or planar laser induced fluorescence (2-D LEF).[1]

In order to use the 2-D LEF technique, a molecule must be selected which is both reasonably abundant and characteristic of the pyrolysis or combustion process of interest. These species are typically diatomic or triatomic radicals which are created and rapidly consumed in the process. Typical species might be NO_2 for a pyrolysis experiment or OH for combustion. The beam from a laser tuned for resonant absorption by the probed species is expanded in one dimension to form a sheet of light. An optical system with its axis normal to the plane of the laser beam is used to image the resulting fluorescence onto the detector. The result is an image of the concentration of the probed species in a slice through the combustion event. Thus one may obtain information which is free of boundary layer effects and which can be complimentary to other diagnostic observations. Key parameters are the selection of the radical to be probed and choice of detector with a major trade-off being between framing rate and sensitivity. In the present study the radicals present in the ignition and combustion of liquid propellants have been characterized. Our goal is to develop this technique with specific application to liquid propellant materials and pursue its application under high pressure conditions.

II. OBSERVATIONS

A. Emission Spectra

The liquids of interest here are composed of hydroxylammonium nitrate (HAN), an aliphatic ammonium nitrate (e.g., isopropylammonium nitrate, IPAN), and water. A brief study of the structures of these molecules suggests that during reaction a number of diatomic radicals might be formed which would be suitable for identifying regions of reaction, including NH, NH_2, CN, and OH. One would also expect NO_2 to be produced during some stages of reaction. The most direct way to obtain evidence of the presence of such species under flame conditions is to introduce small quantities of the appropriate liquids into a flame, in a manner similar to conventional analytical chemistry techniques. This was done by using small custom made burners of various geometries which

---

1. (a) R.K. Hanson, G. Kychakoff, E.C. Rea, Jr., B. Hiller, R.D. Howe, and M.A. Kimball-Linne, Proceedings of the 20th JANNAF Combustion Meeting, CPIA Pub. No. 383, p. 43, 1983. (b) M.J. Dyer and D.R. Crosley, Opt. Lett. Vol. 7, p. 328, 1982. (c) R.J. Cattolica and S.R. Vosen, Sandia Report SAND84-8640, 1984.

contained separate flow channels for hydrogen and an oxidizer (either air or nitrous oxide) which burned as a highly turbulent diffusion flame. A few hundred microliters or less of the liquid was introduced into the flow of air. The air flow tube was approximately 0.8 mm in diameter; the resulting high Reynolds number flow caused the atomization of the liquid into small droplet sizes which were rapidly heated and consumed by the flame. The emissions from the flame were dispersed by a 0.25 m spectrograph and detected by a silicon intensified target (SIT) vidicon tube with an ultraviolet scintillator.

Spectra have been observed during the injection of both aqueous HAN and HAN/IPAN/water mixtures. In all cases the emission was spectrally typical of that from gaseous hydrocarbon flames. Preliminary measurements using a hydrogen/nitrous oxide flame showed that the emission from the radicals OH and NH, which are already present in abundance in the flame, was decreased when the liquid was added. This effect was probably due to cooling of the flame by the addition of the liquid. Subsequently all spectra shown were taken with air as the oxidizer. With HAN injection into the air flame, NH emission ($A^3\pi$-$X^3\Sigma^-$) was positively identified, as shown in Figure 1. Although the SIT tube sensitivity near 335 nm is down about a factor of seven compared to 385 nm, the NH signals were substantially weaker than expected, based on the observations with the hydrogen/nitrous oxide flames. Also observed was broadband emission centered at about 500 nm which was probably due to NO_2. An additional peak in the region of NH_2 emission near 547 nm was observed; positive identification was not made, however. With the injection of HAN/IPAN/water mixes into the flame, NH signals remained weak, CN ($B^2\Sigma^+$-$X^2\Sigma^+$) Figure 2, and CH ($A^2\Delta$-$X^2\pi$) Figure 3, were strong. In this case C_2 ($d^3\pi_g$-$a^3\pi_u$) was clearly present as shown in Figure 4. However, the C_2 intensity is about a factor of ten below that of CN. The unidentified emission was again observed near 547 nm, although with a broader peak than with HAN. Again, the broadband emission characteristic of NO_2 was observed, as seen underlying the C_2 spectrum in Figure 4. From our past experience with similar flames,[2] it is also very likely that NCO is present; its emission would be masked by that of CH in Figure 3 [see Figure 5 of Reference 2].

B. Two-Dimensional Fluorescence Emission

As a first step prior to two-dimensional laser probing of radical concentrations, the spatial distribution of the spontaneously emitting radicals was studied when a droplet was introduced into a flame. The experiment consisted of a hydrogen/air flame stabilized on a $\frac{3}{4}$ mm diameter sintered bronze burner. A droplet of approximately 1 to 2 mm^3 was introduced into the hot gas region immediately above the flame by holding it on a piece of number 18 nickel wire. Under these conditions a droplet typically survived several seconds including a heating phase, sputtering and fizzing, and finally being consumed, usually with a bright flash of light. The emission from the droplet was imaged with an f/10 quartz optic onto a silicon intensified target (SIT) vidicon tube, part of a PARC, Inc. OMA-I system. For the work reported

2. W.R. Anderson, J.A. Vanderhoff, A.J. Kotlar, M.A. DeWilde, and R.A. Beyer, J. Chem. Phys., Vol. 77, p. 1677, 1982.

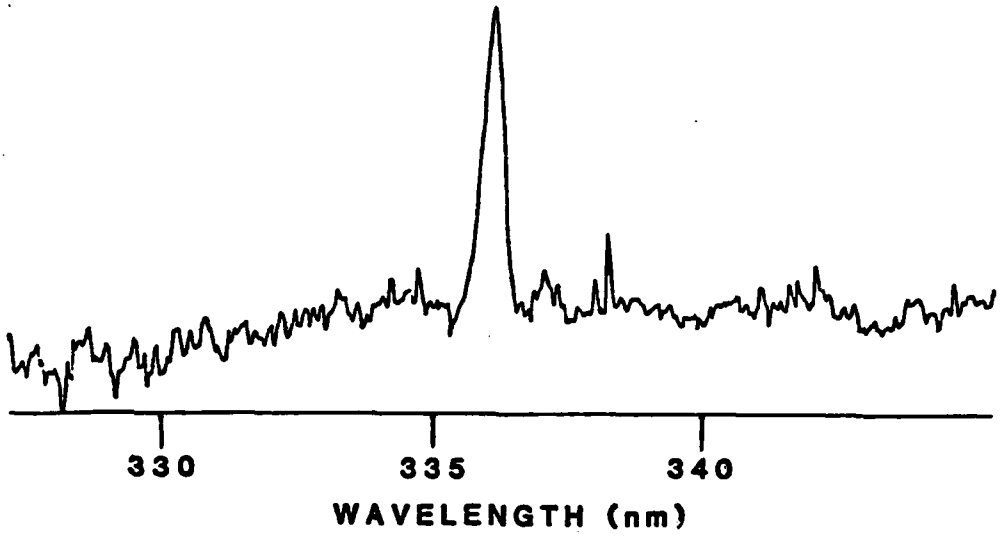


Figure 1. NH ($A^3\pi$-$X^3\Sigma^-$) Emission Resulting from the Injection of HAN Into the Hydrogen/Air Flame. Note the lower signal level compared to the background noise levels in Figures 2-4.

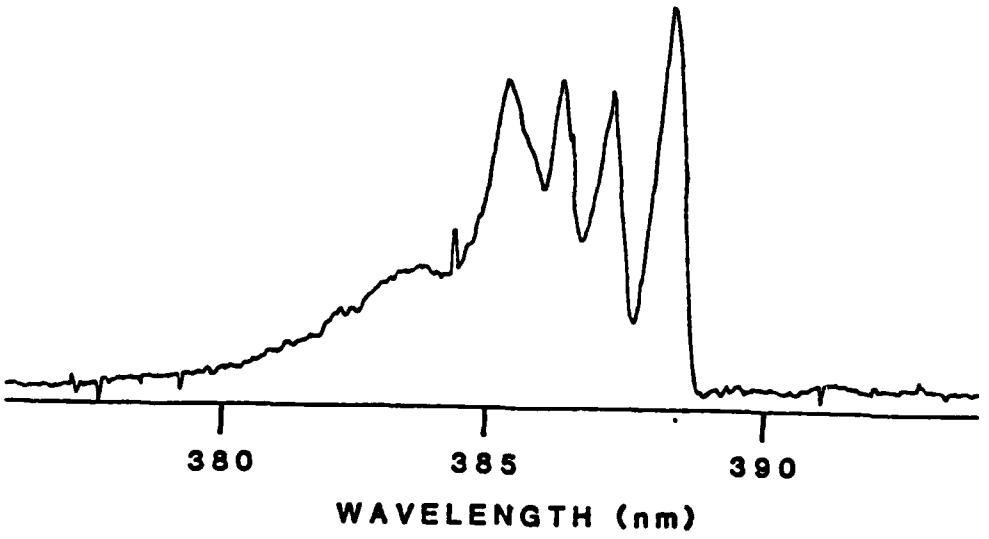


Figure 2. CN ($B^2\Sigma^+$-$X^2\Sigma^+$) Emission Resulting from the Combustion of a Typical HAN/IPAN/Water Propellant in a Hydrogen/Air Flame

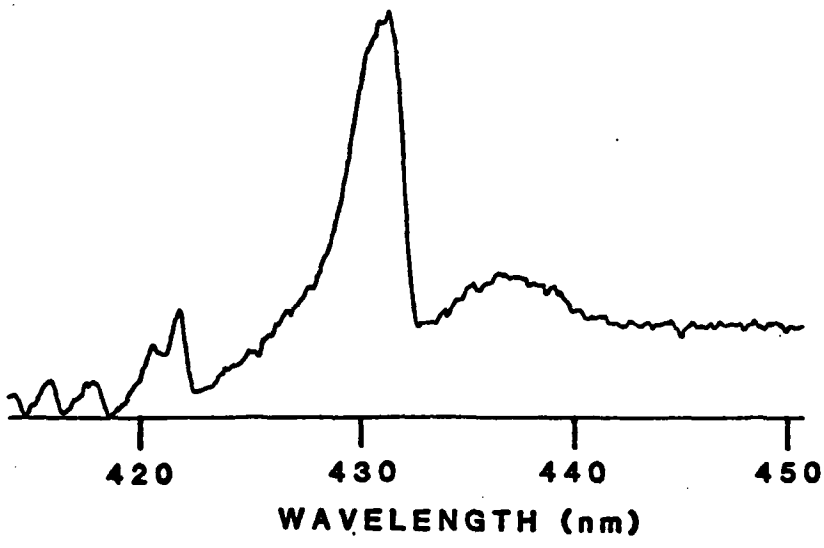


Figure 3. CH (A^2A-$X^2\pi$) Emission from the Combustion of the Same Liquid as Figure 2. Note that CN emission is also present at the shorter wavelengths shown.

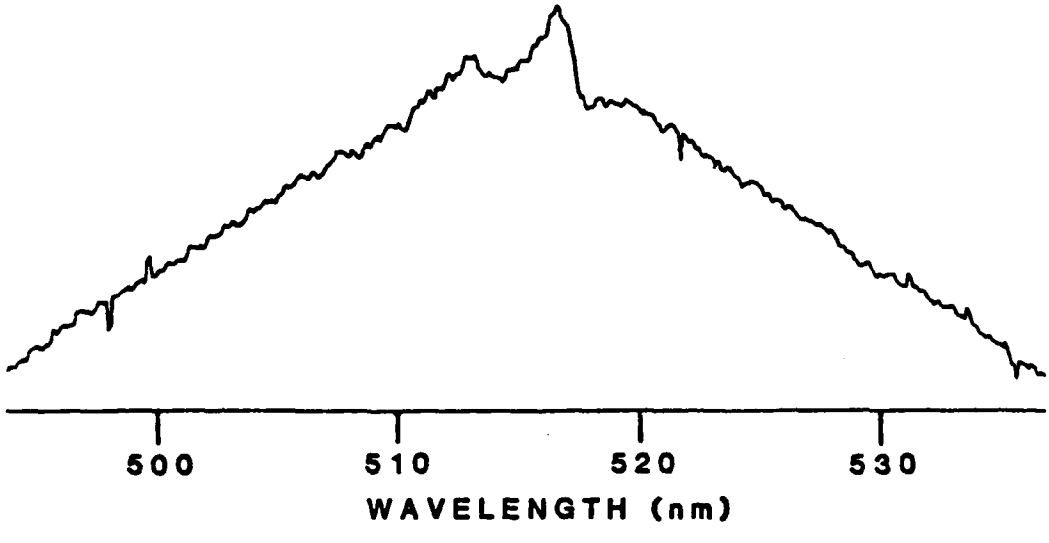


Figure 4. C_2 ($d^3\pi_g$-$a^3\pi_u$) Emission (The Two Distinct Peaks in the Center) Atop a Broad Pedestal of Emission from an Unidentified Species, Probably NO_2

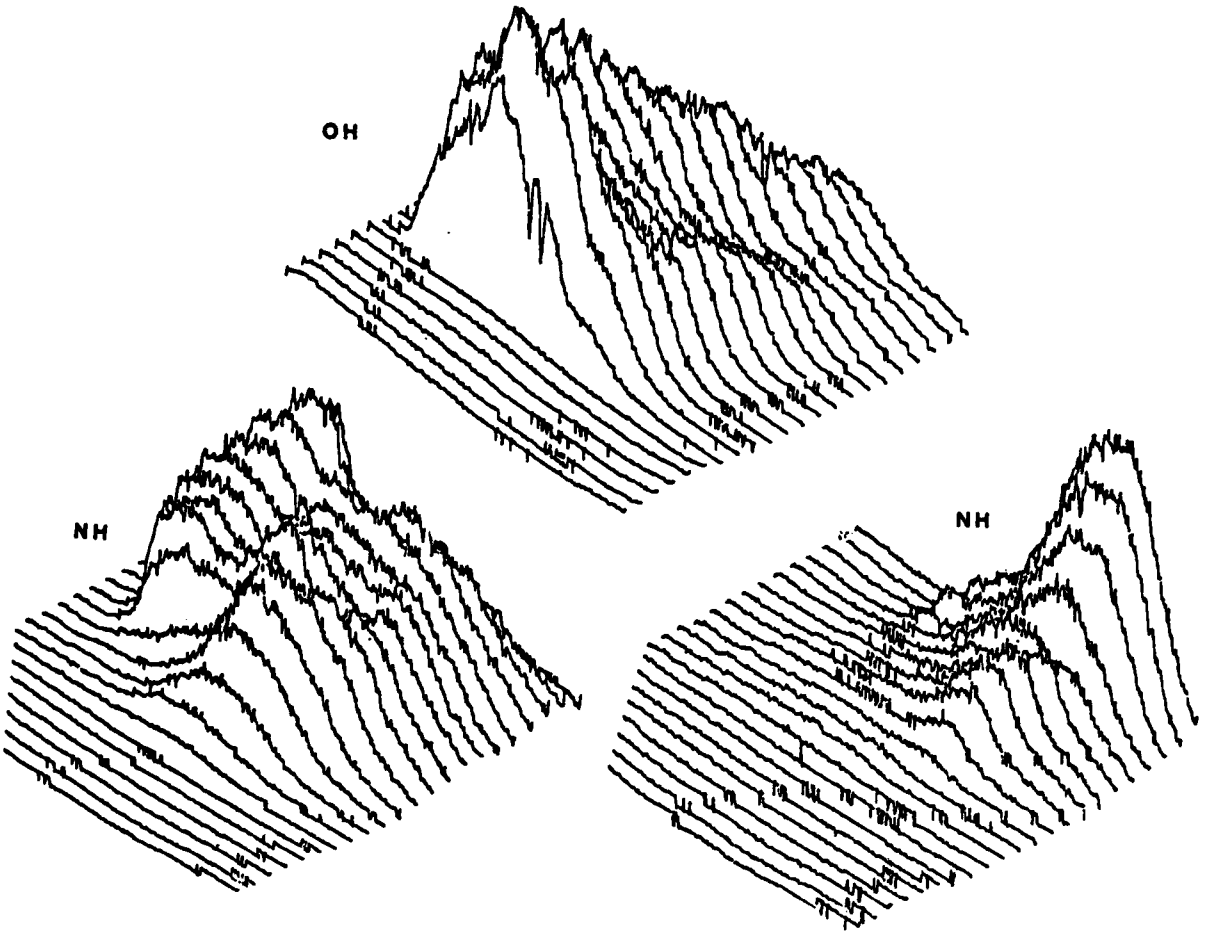


Figure 5. Spatially Resolved Fluorescence from a Liquid Drop Above a Sintered Bronze Burner, Showing OH, and NH from Two Different Drops. The burner surface is between traces 6 and 7 of the plot; the flow flow of hot gases is up and to the right of the figure.

here, the vidicon was set up with a 33 line scan of 500 points each. Although this resolution is somewhat limited, it is adequate for preliminary studies. The video signal was digitized and stored by a dedicated PDP 11/34 laboratory computer. The data were then plotted in a hidden-line manner to show the variations across the imaged area. Various narrow bandpass filters were used on the detector to isolate the emission from individual species.

Spatially resolved emission was recorded for OH, CN, and NH with droplets of propellant "1846." This propellant's composition is 60.8 weight percent HAN, 19.2 weight percent triethanolammonium nitrate (TEAN), and 20% water. Typical plots made with fixed image area are shown in Figure 5 for OH from the flame and NH from two different droplets. Thus the OH plot in Figure 5 can be used to define the position of the burner and flow of hot gases. The two NH plots in Figure 5 show the variability of combustion behavior of two similar drops. The drop shown on the left ignited in place and was swept away with the hot flow. The second NH plot, from a more violent event, shows an

apparent bifurcation and two regions of combustion. The NH emission in this latter plot extends down to the burner surface. The spatial separation of the NH and OH is clear in this figure. Signal strength in emission is certainly more than adequate; in many cases, especially with CN, the detector was saturated in the region of droplet combustion. The limited resolution of the detector (33 lines used, 22 lines shown in the plots) is clearly adequate for many studies. It is also very apparent that reproducibility from droplet to droplet is not good under these conditions, as might be expected. It was not clear when performing the observations that apparent energy release during the event and signal level were correlated well with changes in droplet size.

III. PROGNOSIS FOR PLANAR LASER FLUORESCENCE PROBING

Several factors must be considered in choosing a candidate molecule for probing in these systems. Possible choices of interest here are: OH, NH, CN, C_2, NCO, CH, NO_2, and NH_2. The anticipated behavior would be that NH, NH_2, and possibly NO_2 would be produced in pyrolysis or earlier in the flame, and be rapidly consumed in the flame reaction zone. CN, C_2, CH, and NCO are both created and consumed in the narrow region of combustion. OH is typically much longer lived and can survive well beyond the actual flame region. Spectroscopically, NH_2 and NO_2 are different from the diatomics in that their emission tends to be broad and spread over wider regions. This same property of NO_2 also gives it good absorption of most visible wavelengths, allowing the use of fixed frequency lasers. However, preliminary attempts with laser fluorescence of the pyrolysis gases of these liquids has shown that under at least some conditions almost no NO_2 is formed. Thus care must be taken in choosing it as a target molecule. Of the diatomic species, NH would chemically be the species of choice for studies of chemical reaction early in the combustion process. Unfortunately, the NH optical transitions are in a region where relatively little laser power is available; these emission studies also suggest that the NH which is present does not survive the flame long enough to build to appreciable concentrations in the hot regions. OH has been used in previous 2-D LEF studies of flames, but is of lesser interest here because it survives long after most of the heat release is accomplished; thus it is not a good indicator of narrow regions of flame reaction zone. However, OH has the substantial advantage of being extremely well characterized spectroscopically, and is not easily dismissed as a possible probe species. As mentioned above, CN is generally confined to the reaction zone of a flame. In addition, because of transition strength values, CN might provide signal levels approximately two orders of magnitude above those of OH under similar conditions. The additional attraction of good laser power availability at the right wavelengths also makes CN attractive. C_2 has favorable lifetime and transition strength values, as well as having transitions at wavelengths which are accessible. However, it is not a strong emitter in our studies and may not be present in sufficient abundance to be a good probe species. Other possibilities, NCO and CH, have optical transitions in unfavorable regions from the consideration of laser power for pulsed, tunable lasers.

The above discussion is centered heavily on the concept of one diagnostic pulse per event. Other possibilities are also being considered. These include the use of a high repetition rate copper vapor laser which could excite NO_2 and possibly C_2, and cw argon or krypton lasers, which can excite

NO_2, C_2, and NCO, with detection by high speed camera in both cases. Possible improvements in electronic cameras or other techniques are also being considered to allow higher framing rates.

IV. SUMMARY

Flame emission studies have been performed to identify and to show qualitative relative abundances of radicals present in the combustion of typical liquid propellants. From these observations and spectroscopic considerations, it has been concluded that CN has several advantages as a target molecule for a single pulse experiment. Other approaches which will allow observations which are closer to a high speed movie of radical spatial distributions are also possible and will be pursued.

DISTRIBUTION LIST

No. Of Copies	Organization
12	Administrator Defense Technical Info Center ATTN: DTIC-DDA Cameron Station Alexandria, VA 22304-6145
1	HQ DA DAMA-ART-M Washington, DC 20310
1	Commander US Army Materiel Command ATTN: AMCDRA-ST 5001 Eisenhower Avenue Alexandria, VA 22333-0001
1	Commander Armament R&D Center US Army AMCCOM ATTN: SMCAR-TSS Dover, NJ 07801
2	Commander Armament R&D Center US Army AMCCOM ATTN: SMCAR-TDC Dover, NJ 07801
1	Director Benet Weapons Laboratory Armament R&D Center US Army AMCCOM ATTN: SMCAR-LCB-TL Watervliet, NY 12189
1	Commander US Army Armament, Munitions and Chemical Command ATTN: SMCAR-ESP-L Rock Island, IL 61299
1	Commander US Army Aviation Research and Development Command ATTN: AMSAV-E 4300 Goodfellow Blvd. St. Louis, MO 63120

No. Of Copies	Organization
1	Director US Army Air Mobility Research and Development Laboratory Ames Research Center Moffett Field, CA 94035
4	Commander US Army Research Office ATTN: R. Ghirardelli D. Mann R. Singleton R. Shaw P.O. Box 1221 Research Triangle Park, NC 27709-2211
1	Commander US Army Communications - Electronics Command ATTN: AMSEL-ED Fort Monmouth, NJ 07703
1	Commander ERADCOM Technical Library ATTN: DELSD-L, Reports Section Fort Monmouth, NJ 07703-5301
2	Commander Armament R&D Center US Army AMCCOM ATTN: SMCAR-LCA-G, D.S. Downs J.A. Lannon Dover, NJ 07801
1	Commander Armament R&D Center US Army AMCCOM ATTN: SMCAR-LC-G, L. Harris Dover, NJ 07801
1	Commander Armament R&D Center US Army AMCCOM ATTN: SMCAR-SCA-T, L. Stiefel Dover, NJ 07801

DISTRIBUTION LIST

No. Of Copies	Organization
1	Commander, U.S. Army Missile Command, Research, Development & Engineering Center ATTN: AMSMI-RD Redstone Arsenal, AL 35898
2	Commander US Army Missile Command ATTN: AMSMI-RK, D.J. Ifshin W. Wharton Redstone Arsenal, AL 35898
1	Commander US Army Tank Automotive Command ATTN: AMSTA-TSL Warren, MI 48090
1	Director US Army TRADOC Systems Analysis Activity ATTN: ATAA-SL White Sands Missile Range, NM 88002
1	Commandant US Army Infantry School ATTN: ATSH-CD-CSO-OR Fort Benning, GA 31905
1	Commander US Army Development and Employment Agency ATTN: MODE-TED-SAB Fort Lewis, WA 98433
1	Office of Naval Research Department of the Navy ATTN: R.S. Miller, Code 432 800 N. Quincy Street Arlington, VA 22217
1	Commander Naval Air Systems Command ATTN: J. Ramnarace, AIR - 54111C Washington, D.C. 20360
5	Commander Naval Research Laboratory ATTN: L. Harvey J. McDonald E. Oran J. Shnur R. J. Doyle, Code 6110 Washington, D.C. 20375
1	Commander Naval Surface Weapons Center ATTN: J.L. East, Jr., G-23 Dahlgren, VA 22448
2	Commander Naval Surface Weapons Center ATTN: R. Bernecker, R-13 G.B. Wilmot, R-16 Silver Spring, MD 20910
1	Commander Naval Weapons Center ATTN: R.L. Derr, Code 389 China Lake, CA 93555
2	Commander Naval Weapons Center ATTN: Code 3891, T. Boggs K.J. Graham China Lake, CA 93555

DISTRIBUTION LIST

No. Of Copies	Organization
1	Commanding Officer Naval Underwater Systems Center Weapons Dept. ATTN: R.S. Lazar/Code 36301 Newport, RI 02840
1	Superintendent Naval Postgraduate School Dept. of Aeronautics ATTN: D.W. Netzer Monterey, CA 93940
4	AFRPL/DY, Stop 24 ATTN: R. Corley R. Geisler J. Levine D. Weaver Edwards AFB, CA 93523-5000
1	AFRPL/MKPB, Stop 24 ATTN: B. Goshgarian Edwards AFB, CA 93523-5000
2	AFOSR ATTN: L.H. Caveny J.M. Tishkoff Bolling Air Force Base Washington, DC 20332
1	AFWL/SUL Kirtland AFB, NM 87117
1	Air Force Armament Laboratory ATTN: AFATL/DLODL Eglin AFB, FL 32542-5000
1	NASA Langley Research Center Langley Station ATTN: G.B. Northam/MS 168 Hampton, VA 23365
4	National Bureau of Standards ATTN: J. Hastie M. Jacox T. Kashiwagi H. Semerjian US Department of Commerce Washington, DC 20234
1	Aerojet Solid Propulsion Co. ATTN: P. Micheli Sacramento, CA 95813
1	Applied Combustion Technology, Inc. ATTN: A.M. Varney P.O. Box 17885 Orlando, FL 32860
2	Applied Mechanics Reviews The American Society of Mechanical Engineers ATTN: R.E. White A.B. Wenzel 345 E. 47th Street New York, NY 10017
2	Atlantic Research Corp. ATTN: M.K. King 5390 Cherokee Avenue Alexandria, VA 22314
1	Atlantic Research Corp. ATTN: R.H.W. Waesche 7511 Wellington Road Gainesville, VA 22065
1	AVCO Everett Rsch. Lab. Div. ATTN: D. Stickler 2385 Revere Beach Parkway Everett, MA 02149
1	Battelle Memorial Institute Tactical Technology Center ATTN: J. Huggins 505 King Avenue Columbus, OH 43201
2	Exxon Research & Eng. Co. Government Research Lab ATTN: A. Dean M. Chou P.O. Box 48 Linden, NJ 07036

DISTRIBUTION LIST

No. Of Copies	Organization
1	Ford Aerospace and Communications Corp. DIVAD Division Div. Hq., Irvine ATTN: D. Williams Main Street & Ford Road Newport Beach, CA 92663
1	General Electric Armament & Electrical Systems ATTN: M.J. Bulman Lakeside Avenue Burlington, VT 05401
1	General Electric Co. ATTN: Alan Wait Rd 3, Plains Rd Ballston Spa, NY 12020
1	General Electric Ordnance Systems ATTN: J. Mandzy 100 Plastics Avenue Pittsfield, MA 01203
1	General Motors Rsch Labs Physics Department ATTN: R. Teets Warren, MI 48090
3	Hercules, Inc. Allegany Ballistics Lab. ATTN: R.R. Miller P.O. Box 210 Cumberland, MD 21501
3	Hercules, Inc. Bacchus Works ATTN: K.P. McCarty P.O. Box 98 Magna, UT 84044
1	Honeywell, Inc. Government and Aerospace Products ATTN: D.E. Broden/ MS MN50-2000 600 2nd Street NE Hopkins, MN 55343
1	IBM Corporation ATTN: A.C. Tam Research Division 5600 Cottle Road San Jose, CA 95193
2	Director Lawrence Livermore National Laboratory ATTN: C. Westbrook M. Costantino P.O. Box 808 Livermore, CA 94550
1	Lockheed Missiles & Space Co. ATTN: George Lo 3251 Hanover Street Dept. 52-35/B204/2 Palo Alto, CA 94304
1	Los Alamos National Lab . ATTN: B. Nichols T7, MS-B284 P.O. Box 1663 Los Alamos, NM 87545
1	University of Michigan Gas Dynamics Laboratory Aerospace Engineering Bldg. ATTN: G. M. Faeth Ann Arbor, MI 48109-2140
1	Paul Gough Associates, Inc. ATTN: P.S. Gough 1048 South Street Portsmouth, N.H. 03801
2	Princeton Combustion Research Laboratories, Inc. ATTN: M. Summerfield N.A. Messina 475 US Highway One Monmouth Junction, NJ 08852
1	Hughes Aircraft Company ATTN: T.E. Ward 8433 Fallbrook Avenue Canoga Park, CA 91303

DISTRIBUTION LIST

No. Of Copies	Organization
1	Rockwell International Corp. Rocketdyne Division ATTN: J.E. Flanagan/HB02 6633 Canoga Avenue Canoga Park, CA 91304
4	Sandia National Laboratories Combustion Sciences Dept. ATTN: R. Cattolica S. Johnston P. Mattern D. Stephenson Livermore, CA 94550
1	Science Applications, Inc. ATTN: R.B. Edelman 23146 Cumorah Crest Woodland Hills, CA 91364
1	Science Applications, Inc. ATTN: H.S. Pergament 1100 State Road, Bldg. N Princeton, NJ 08540
4	SRI International ATTN: G. Smith D. Crosley D. Golden 333 Ravenswood Avenue Menlo Park, CA 94025
1	Stevens Institute of Tech. Davidson Laboratory ATTN: R. McAlevy, III Hoboken, NJ 07030
1	Teledyne McCormack-Selph ATTN: C. Leveritt 3601 Union Road Hollister, CA 95023
1	Thiokol Corporation Elkton Division ATTN: W.N. Brundige P.O. Box 241 Elkton, MD 21921
3	Thiokol Corporation Huntsville Division ATTN: R. Glick Huntsville, AL 35807
1	Thiokol Corporation Wasatch Division P.O. Box 524 Brigham City, UT 84302
1	United Technologies ATTN: A.C. Eckbreth East Hartford, CT 06108
2	United Technologies Corp. ATTN: R.S. Brown R.O. McLaren P.O. Box 358 Sunnyvale, CA 94088
1	Universal Propulsion Company ATTN: H.J. McSpadden Black Canyon Stage 1 Box 1140 Phoenix, AZ 85029
1	Veritay Technology, Inc. ATTN: E.B. Fisher 4845 Millersport Highway P.O. Box 305 East Amherst, NY 14051-0305
1	Brigham Young University Dept. of Chemical Engineering ATTN: M.W. Beckstead Provo, UT 84601
1	California Institute of Tech. Jet Propulsion Laboratory ATTN: MS 125/159 4800 Oak Grove Drive Pasadena, CA 91103
1	California Institute of Technology ATTN: F.E.C. Culick/MC 301-46 204 Karman Lab. Pasadena, CA 91125

DISTRIBUTION LIST

No. Of Copies	Organization
1	University of California, Berkeley Mechanical Engineering Dept. ATTN: J. Daily Berkeley, CA 94720
1	University of California Los Alamos Scientific Lab. ATTN: T.D. Butler P.O. Box 1663, Mail Stop B216 Los Alamos, NM 87545
2	University of California, Santa Barbara Quantum Institute ATTN: K. Schofield M. Steinberg Santa Barbara, CA 93106
1	University of Southern California Dept. of Chemistry ATTN: S. Benson Los Angeles, CA 90007
1	Case Western Reserve Univ. Div. of Aerospace Sciences ATTN: J. Tien Cleveland, OH 44135
1	Cornell University Department of Chemistry ATTN: E. Grant Baker Laboratory Ithaca, NY 14853
1	Univ. of Dayton Rsch Inst. ATTN: D. Campbell AFRPL/PAP Stop 24 Edwards AFB, CA 93523
1	University of Florida Dept. of Chemistry ATTN: J. Winefordner Gainesville, FL 32611
3	Georgia Institute of Technology School of Aerospace Engineering ATTN: E. Price W.C. Strahle B.T. Zinn Atlanta, GA 30332
1	University of Illinois Dept. of Mech. Eng. ATTN: H. Krier 144MEB, 1206 W. Green St. Urbana, IL 61801
1	Johns Hopkins University/APL Chemical Propulsion Information Agency ATTN: T.W. Christian Johns Hopkins Road Laurel, MD 20707
1	University of Minnesota Dept. of Mechanical Engineering ATTN: E. Fletcher Minneapolis, MN 55455
	Pennsylvania State University Applied Research Laboratory ATTN: K. K. Kuo H. Palmer M. Micci University Park, PA 16802
1	Polytechnic Institute of NY Graduate Center ATTN: S. Lederman Route 110 Farmingdale, NY 11735
2	Princeton University Forrestal Campus Library ATTN: K. Brezinsky I. Glassman P.O. Box 710 Princeton, NJ 08540

DISTRIBUTION LIST

No. Of Copies	Organization
1	Princeton University MAE Dept. ATTN: F.A. Williams Princeton, NJ 08544
1	Purdue University School of Aeronautics and Astronautics ATTN: J.R. Osborn Grissom Hall West Lafayette, IN 47907
2	Purdue University School of Mechanical Engineering ATTN: N.M. Laurendeau S.N.B. Murthy TSPC Chaffee Hall West Lafayette, IN 47906
1	Rensselaer Polytechnic Inst. Dept. of Chemical Engineering ATTN: A. Fontijn Troy, NY 12181
1	Stanford University Dept. of Mechanical Engineering ATTN: R. Hanson Stanford, CA 94305
1	University of Texas Dept. of Chemistry ATTN: W. Gardiner Austin, TX 78712
10	Central Intelligence Agency Office of Central Reference Dissemination Branch Room GE-47 Washington, D.C. 20502
1	Director U.S. Army Missile & Space Intelligence Center ATTN: AIAMS-YDL Redstone Arsenal, AL 35898-5500
1	University of Utah Dept. of Chemical Engineering ATTN: G. Flandro Salt Lake City, UT 84112
1	Virginia Polytechnic Institute and State University ATTN: J.A. Schetz Blacksburg, VA 24061
	Aberdeen Proving Ground
	Dir, USAMSAA ATTN: AMXSY-D AMXSY-MP, H. Cohen
	Cdr, USATECOM ATTN: AMSTE-TO-F
	Cdr, CRDC, AMCCOM ATTN: SMCCR-RSP-A SMCCR-MU SMCCR-SPS-IL

USER EVALUATION SHEET/CHANGE OF ADDRESS

This Laboratory undertakes a continuing effort to improve the quality of the reports it publishes. Your comments/answers to the items/questions below will aid us in our efforts.

1. BRL Report Number_____ Date of Report_____

2. Date Report Received_____

3. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which the report will be used.)_____

4. How specifically, is the report being used? (Information source, design data, procedure, source of ideas, etc.)_____

5. Has the information in this report led to any quantitative savings as far as man-hours or dollars saved, operating costs avoided or efficiencies achieved, etc? If so, please elaborate._____

6. General Comments. What do you think should be changed to improve future reports? (Indicate changes to organization, technical content, format, etc.)

CURRENT ADDRESS

Name

Organization

Address

City, State, Zip

7. If indicating a Change of Address or Address Correction, please provide the New or Correct Address in Block 6 above and the Old or Incorrect address below.

OLD ADDRESS

Name

Organization

Address

City, State, Zip

(Remove this sheet along the perforation, fold as indicated, staple or tape closed, and mail.)

FOLD HERE

Director
U.S. Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T
Aberdeen Proving Ground, MD 21005-5066

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

BUSINESS REPLY MAIL
FIRST CLASS PERMIT NO 12062 WASHINGTON, DC
POSTAGE WILL BE PAID BY DEPARTMENT OF THE ARMY

Director
U.S. Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T
Aberdeen Proving Ground, MD 21005-9989

FOLD HERE

END

FILMED

3 -86

DTIC